Dynamic-Autonomy for Urban Search and Rescue

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Abstract

At the 2002 AAAI Robotics Competition and Exhibition, the Idaho National Engineering and Environmental Laboratory (INEEL) demonstrated a robot that can adjust its level of autonomy on the fly, leveraging its own, intrinsic intelligence to meet whatever level of control was handed down from the user. The robot had the ability to actively protect itself and the environment as it navigated through the USAR environment. In addition, the robot continuously assessed and adapted to changes in its own perceptual capabilities. The INEEL also demonstrated an interface for supporting mixed-initiative interaction between the operator and human. The interface displays an abstracted representation of the robot's experience and exploits sensor-suites and fusion algorithms that enhance capabilities for sensing, interpreting, and "understanding" environmental features. This paper reports on the current robotic system including hardware, sensor suite, control architecture, and interface system.

I. INTRODUCTION

This paper describes research being conducted at the Idaho National Engineering and Environmental Laboratory (INEEL) in the area of robot control architectures and human robot interaction (HRI). The INEEL is researching and developing new and innovative tools for synergistic interaction between autonomous robots and human operators, peers and supervisors. The goal is to interleave multiple levels of human intervention into the functioning of a robotic system that will, in turn, learn to adapt its own level of initiative. For a robotic system to gracefully accept a full spectrum of intervention possibilities, interaction issues cannot be handled merely as augmentations to a control system. Instead, opportunities for operator intervention must be incorporated as an integral part of the robot's intrinsic intelligence. The robot must be imbued with the ability to accept different levels and frequencies of intervention. Moreover, for autonomous capabilities to evolve, the robot must be able to recognize when help is needed from an operator and/or other robot and learn from these interactions.

Many of the robotic solutions demonstrated at the competition had been designed with Urban Search and Rescue in mind. In contrast, our research is motivated by operational experience at the INEEL in conducting remote characterization of hazardous environment using robotic platforms. Mobile robots used within DOE environments have been either teleoperated or fully autonomous. Teleoperated systems have often failed to address the limitations of telepresence inherent to current communication technologies. On the other hand, attempts to build and use autonomous systems have failed to acknowledge the inevitable boundaries to what the robot can perceive, understand, and decide apart from human input. Both approaches have failed to build upon the strengths of the robot and the human working as a cohesive unit. Instead, our approach has been to craft a dynamic autonomy control architecture, which permits the user to move between these two poles. Sliding autonomy, as demonstrated in Edmonton, supports changing communication, cognitive, perceptual and action capabilities of the user and robot.

II. ROBOT IMPLEMENTATION

In developing the mixed-initiative control architectures, we used a modified ATRVJr robot platform commercially available from iRobot. The ATRVJr was fitted with a Sony CCD camera that can pan, tilt and zoom to provide visual feedback to the user. The robot also uses this camera in the autonomous modes to characterize the environment and can automatically track people and objects, permitting the robot to autonomously follow a human even at high speeds based on autonomous behaviors developed at the INEEL. This autonomous tracking capability was also demonstrated at AAAI as part of the exhibition program.

During the urban search and rescue competition, one of the most useful augmentations to the robot proved to be the addition of a forward looking infrared (FLIR) camera to an ATRVJr robot and has developed software that allows the data from this camera to be integrated into the robot control architecture. Fused data from the FLIR and CCD cameras permits both autonomous and human-assisted recognition of relevant heat sources including human heat signatures. This also allowed us to distinguish between "live" and "dead" victims within the USAR environment.

Figure 1: Thermal camera mounted on robot

To accomplish the guarded motion capabilities which proved invaluable in the USAR environment, perceptual algorithms running on the robot fuse a variety of range sensor information. A laser range finder is mounted on the front, and 17 sonar are located around the mid-section of the robot. The robot also has highly sensitive bump strips in the rear and front that register if anything has been touched.

To protect the top of the robot, especially the cameras, we have also added an array of infrared proximity sensors that indicate when an object is less than nine inches from the robot. Additional infrared proximity sensors have been placed on the bottom of the robot and point ahead of the robot towards the ground in order to prevent the robot from traveling into open space (e.g. traveling off of a landing down a stairway). Together these sensors provide a field of protection around the robot and allow the operator to command the robot with full confidence.

However, obstacle avoidance is not sufficient for optimal human-robot interaction. The USAR environment included forms of uneven terrain such as rubble, which the robot should be able to recognize and respond to. The robot has inertial sensors that provide acceleration data in three dimensions. This data is fused with current draw from the batteries and acceleration and velocity information from the wheel encoders to produce a measure of the "unexpected" resistance to motion encountered by the robot. The user can choose to set a resistance limit which will automatically stop the robot once the specified threshold has been exceeded. The resistance limit is valuable not only for rough terrain, but in situations when the user needs to override the "safe motion" capabilities to do things like push chairs and boxes out of the way or push doors open. In addition, the robot has tilt sensors that indicate pitch and roll.

Figure 2: Instrumented robot platform

To permit deployment within shielded structures, we have developed a customized communication protocol, which allows very low bandwidth communications to pass over a serial radio link only when needed. The interface itself then unfolds these simple packets into a comprehensive interface. Although our visual link and wireless ethernet link were subject to dropouts during the competition, the 900Mhz data link that we used to transmit this protocol suffered no data loss throughout the entire competition and exhibition.

III. CONTROL ARCHITECTURE

Within the last five years, researchers have begun in earnest to examine the possibility for robots to support multiple levels of user intervention. Much of this work has focused on providing the robot with the ability to accept high level verbal, graphical, and gesture-based commands [1], [2], [3]. Others have implemented robots that understand the limitations of their autonomous capabilities and can query the user for appropriate assistance [4], [5]. Goodrich et al. [6] have performed experiments which involve comparing the performance of human-robot pairs using different modes of human intervention. However, very little work has emphasized true peer to peer interactions where the robot is actually able to shift modes of autonomy as well as the user. Sholtz [7] discusses the need for this kind of peer-peer interaction, and provides categories of human intervention including supervisory, peer to peer and mechanical interaction (e.g. teleoperator).

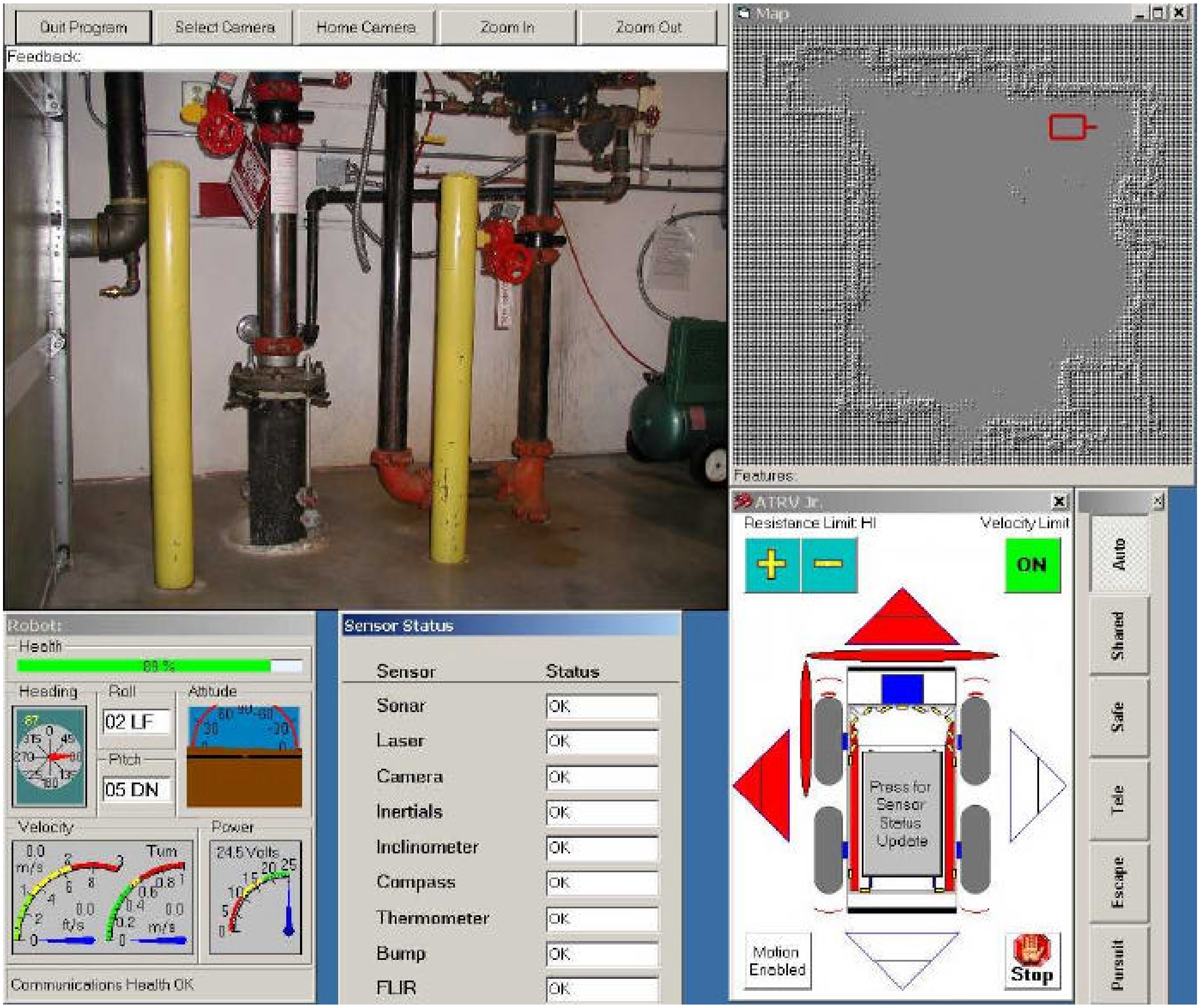

Figure 3: Current interface used for mixed-initiative control of the robot

Our research to date has developed a control architecture that spans these categories, supporting the following modes of remote intervention:

1. Teleoperation
2. Safe Mode
3. Shared Control
4. Full Autonomy

For each of these levels of autonomy, perceptual data is fused into a specialized interface (shown in figure 3) that provides the user with abstracted auditory, graphical and textual representations of the environment and task that are appropriate for the current mode. Currently, this interface is used on a touch screen tablet PC made by Fujitsu Corp.. Within this interface, blockages are shown as red ovals and resistance to motion is shown as arcs emanating from the wheels. The robot relays a great deal of synthesized, high-level information (including suggestions and requests for help) to the user in a textual form using the feedback textbox within the image window. Also note that the robot provides textual reports on environmental features at the bottom of the map window and reports on communications status at the bottom of the robot status window. The robot status window provides a variety of information about the status of the robot including pitch and roll, power, heading, speed and a fusion of this information into a single measurement of “health.”

The user can move the robot by touching the arrows or may use a joystick or other game controller. It is possible to pan and tilt the camera automatically by touching regions of the visual image. Currently, we are still working to integrate the on-the-fly mapping capabilities with the interface shown in figure 3. As we continue this task, the interface will allow a number of autonomous tasks (e.g. searching a specified region or going to a goal location) to be issued by interacting with the map itself.

A. Teleoperation

We have taken the interaction substrate used in previous INEEL teleoperated robotic systems and revamped it through feedback from people who have deployed such systems. Within teleoperation mode, the user has full, continuous control of the robot at a low level. The robot takes no initiative except to stop once it recognizes that communications have failed.

B. Safe Mode

Within safe mode, the user directs the movements of the robot, but the robot takes initiative to protect itself. In doing so, this mode allows the user to issue motion commands with impunity, greatly accelerating the speed and confidence with which the user can accomplish remote tasks. The robot assesses its own status and surrounding environment to decide whether commands are safe. For example, the robot has excellent perception of the environment and will stop its motion just before a collision, placing minimal limits on the user to take the robot's immediate surroundings into account. The robot also continuously assesses the validity of its diverse sensor readings and communication capabilities. The robot will refuse to undertake a task if it does not have the ability (i.e., sufficient power or perceptual resources) to safely accomplish it.

C. Shared Control

The robot takes the initiative to choose its own path, responds autonomously to the environment, and works to accomplish local objectives. However, this initiative is primarily reactive rather than deliberative. In terms of navigation, the robot responds only to its local (~ 6-10 meter radius), sensed environment. Although the robot handles the low level navigation and obstacle avoidance, the user supplies intermittent input, often at the robot's request, to guide the robot in general directions. The problem of deciding how and when the robot should ask for help has been a major line of HRI enquiry and will be a major issue in our upcoming human subject experiments. The most successful runs during the USAR competition where run primarily in this mode of autonomy where the robot was allowed to steer, but was guided by intermittent user input.

D. Full Autonomy

In this mode the robot performs global path planning to select its own routes, requiring no user input except high-level tasking such as "follow that target" or "search this area" specified by drawing a circle around a given area on the map created by the robot. This map is built on the fly and uses frontier-based exploration and localization to perform searches over large areas including multiple rooms and corridors. The user interacts with the map to specify tasks and can guide the robot and infuse knowledge at an abstract level by selecting areas of interest and identifying sensed environmental features, which then become included within the map. At the time of the USAR competition the mapping was not yet functioning together with the control architecture. Shortly thereafter, the mapping was shown to work together with all four modes of autonomy described above.

The absence of mapping proved to be the greatest hindrance to the human-robot interaction during the USAR competition. Without the global representation of the environment, it was difficult for the operator to remember where the robot was within the environment. Although the robot had the ability to autonomously drive itself throughout the USAR environment, it lacked the ability to do global path planning based on a map. Despite the lack of on-the-fly mapping, the multiple levels of operator intervention utilized at the competition greatly improved on the opportunities provided to the operators of a strictly teleoperated system. In fact, throughout the competition and exhibition, many people were given the opportunity to drive the robotic system in its different modes of autonomy. The interface required minimal instruction and allowed the users to navigate remotely throughout the AAAI exhibition arena.

IV. CONCLUSIONS

The INEEL is currently exploring new ground in the area of human interaction with robots. The motivation for our work is the development of flexible human-robot teams to support the performance of tasks within human-hazardous environments. Utilizing a robot equipped with robust sensors and intelligence, we have developed a human-robot control system and associated interfaces that promote mutual-initiative between the human operator and the robot. The robot is often able to make better judgments about its environment (i.e., local navigation) than distal human controllers. Consequently, we have created modes of control where the robot monitors human command input and infers the need to supplement or override human action. The robot has the power to refuse to undertake commands from the user that are deemed by the robot to pose a threat to itself or its environment. This engenders a host of new questions, especially in regard to how an autonomous and mobile robot can infer intervention points. Within our implementation, human error loses much of its sting because the robot is able to countermand dangerous commands. At the same time, we have provided means for the human to override robot initiative and to configure the robotic initiative for specific tasks and environments. In this way, the human and robot become true team partners who can support and compensate for one another to adapt to new challenges.

V. ACKNOWLEDGEMENTS

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